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Broadband Microwave and W-Band Characterization of BeO-SiC and AlN-Based Lossy Dielectric Composites for Vacuum Electronics

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Abstract: *The complex* dielectric *permittivity properties of lossy ceramic materials used in vacuum electronics are presented. The studies include broadband room temperature behavior in the 0.1-18 GHz range and in W-Band (75-110 GHz). Variable temperature measurements of selected materials at 94 GHz are also presented.*

Keywords: ceramics; instabilities; dielectrics

Introduction

Electrically lossy ceramic materials are used extensively in vacuum electronic (VE) devices for preventing instabilities, reducing reflections, adjusting cavity quality factors, and controlling electromagnetic dispersion and growth rates. While many of the more common low-loss materials are well characterized, detailed dielectric studies of the specialized lossy ceramics of particular importance to VE devices are much less common. The most typical lossy materials used in VE devices are based on the BeO-SiC system, and while they are well-characterized at a limited number of frequencies, they are not well-studied over the entire microwave band and are even less well-understood at W-Band (75-110 GHz). Newly emerging types of lossy materials are based on composites of AlN with various additives, such as SiC or glassy carbon, and again they are often poorly characterized, or in many cases data are completely lacking. Having accurate properties data over a wide range of frequencies and temperatures is important for designing vacuum electronic devices with modern computer codes, particularly to achieve first-pass design success.

Results

The paper will first present broadband (0.1-18 GHz) room temperature measurements of the microwave properties of a variety of commercial vacuum-compatible lossy ceramics, including those based on BeO-SiC, AlN-SiC, and AlN-glassy carbon. The evolution of the frequency-dependent behavior of the complex dielectric permittivity $\varepsilon=\varepsilon'-j\varepsilon''$ as the concentration of lossy additive is increased will be given particular attention, along with physical insight into the underlying mechanisms of polarization and loss. An example of the measured microwave properties of a family of AlN-SiC composites is shown in Fig. 1, which shows the impact of varying the volume fraction of SiC on the frequency-dependent permittivity. The observed dielectric behavior for a number

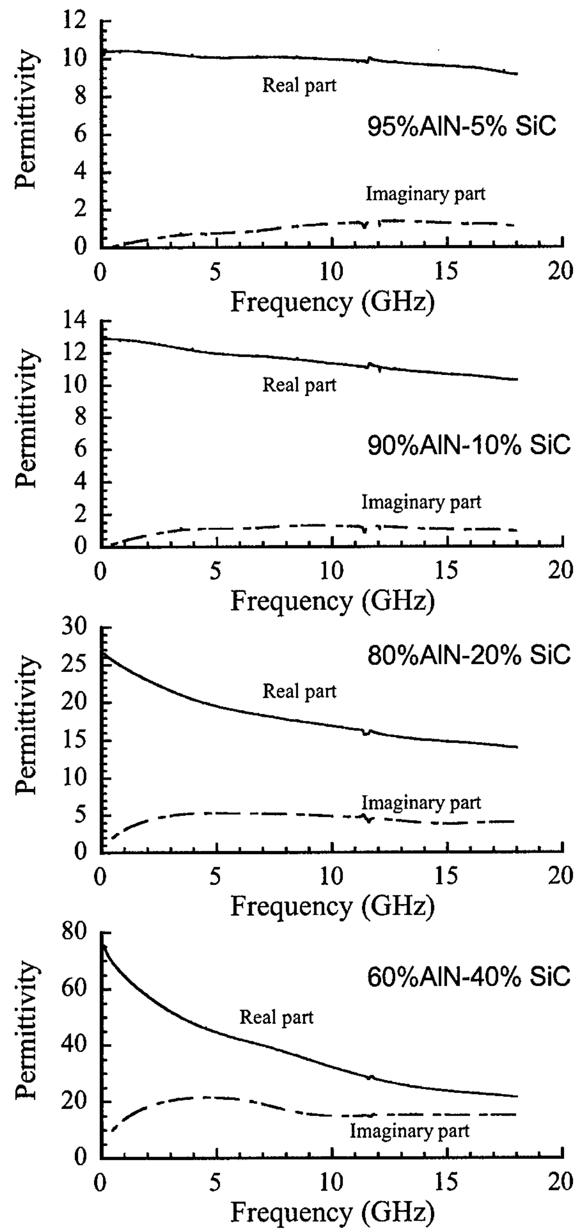

Figure 1. Measured broadband microwave complex permittivity of AlN-SiC composites at room temperature.

of such composite systems will be compared to the results of first-principles, microstructure-level simulations of composite dielectric properties.

permittivity in W-band, a cavity-based system has been devised and implemented. The apparatus uses a TE_{011} cavity containing a small cylindrical sample of dielectric.

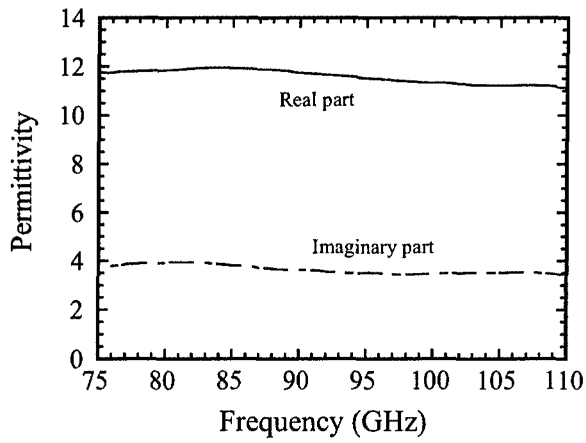

Figure 2. W-band complex room temperature permittivity of 80%BeO-20%SiC obtained using the four-measurement technique.

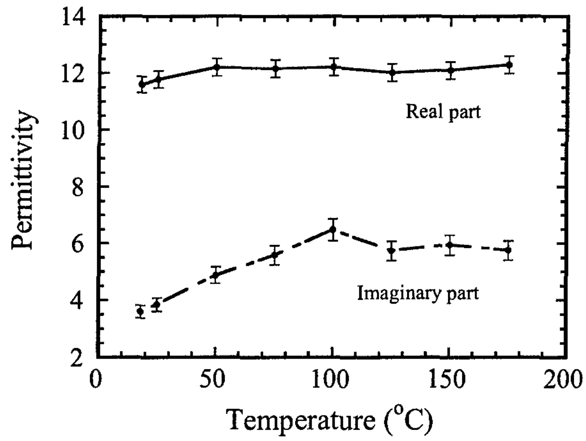

Figure 3. Temperature-dependent complex permittivity of 80%BeO-20%SiC at 94GHz measured using cavity techniques.

A second portion of the paper will deal with measurement techniques for accurately obtaining the W-band (75-110 GHz) dielectric properties of lossy ceramics. This will include a discussion of an improved room temperature, WR-10 waveguide-based method involving measurements of S_{11} from two different samples each with two different reactive terminations. This "four-measurement" technique eliminates spurious solutions to the S_{11}-to-complex permittivity conversion process, and results in much more accurate data. The results for 80%BeO-20%SiC material using the four-measurement technique are shown in Fig. 2. Data has also been obtained for high thermal conductivity AlN-based composite materials using this technique. For making variable-temperature measurements of complex

The cavity is suspended inside an inert atmosphere enclosure and the temperature of the entire cavity (and the sample within) is regulated using a thermocouple, cartridge heaters, and a commercial controller. Changes in resonant frequency and quality factor, after accounting for mechanical expansion of the cavity, are converted to temperature-dependent complex permittivity values using a finite-element electromagnetics code. Temperature-dependent data on BeO-SiC (shown in Fig. 3) and AlN-based lossy composites in the 25-200 °C range will be presented.

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